First measurement of Non-prompt D_s^+ meson production in Pb-Pb collisions with ALICE

XXXII INTERNATIONAL SEMINAR of NUCLEAR and SUBNUCLEAR PHYSICS
11 June 2021

Speaker: **Stefano Politanò**

Politecnico and INFN Torino,

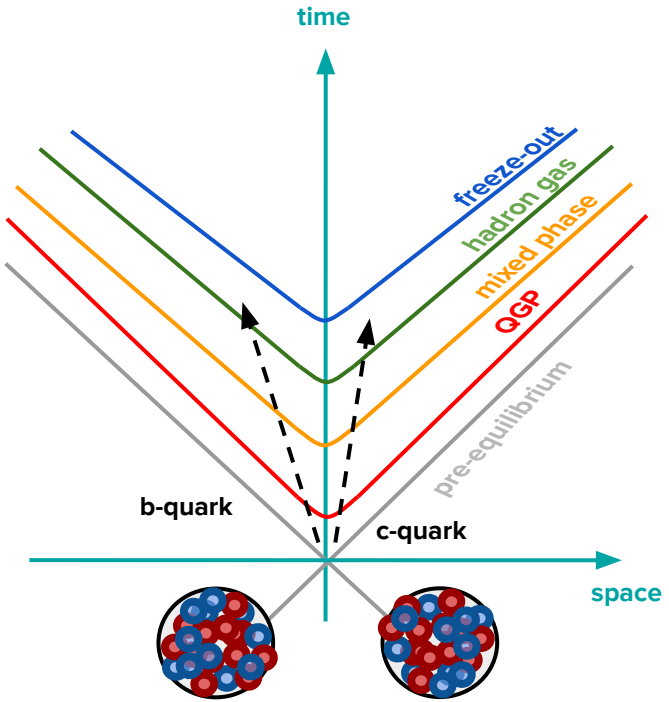
stefano.politano@cern.ch

Istituto Nazionale di Fisica Nucleare
SEZIONE DI TORINO

Physics motivation

Theoretical calculations predict a phase transition from ordinary nuclear matter to a colour-deconfined medium, called quark-gluon plasma (QGP)

- created in ultra-relativistic heavy-ion collisions
- heavy-quark produced in shorter time scales than QGP formation
  - ➡ experience full system evolution
  - ➡ interact with medium constituents
- strange quark production enhanced w.r.t. pp collisions
  - ➡ strange heavy-flavour hadrons production enhanced



PRC 84 (2014)034906

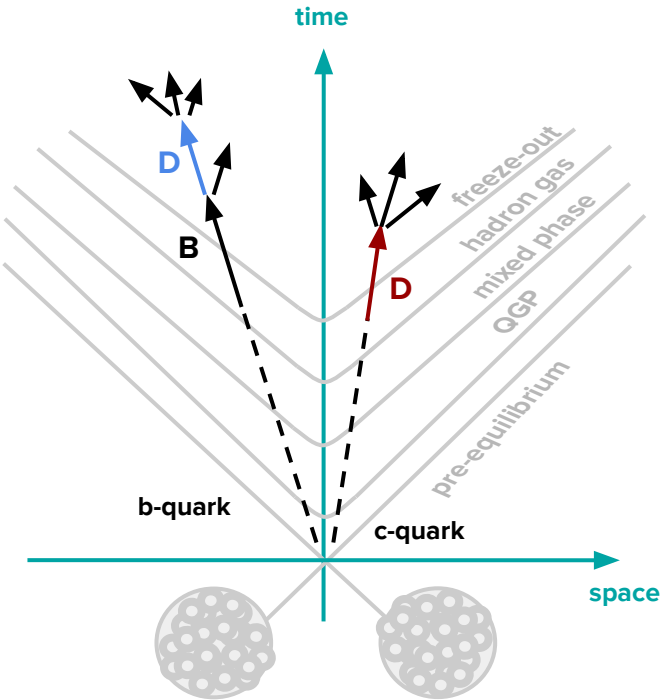
Physics motivation

Theoretical calculations predict a phase transition from ordinary nuclear matter to a colour-deconfined medium, called quark-gluon plasma (QGP)

- created in ultra-relativistic heavy-ion collisions
- heavy-quark produced in shorter time scales than QGP formation
  - ➡ experience full system evolution
  - ➡ interact with medium constituents
- strange quark production enhanced w.r.t. pp collisions
  - ➡ strange heavy-flavour hadrons production enhanced
- Prompt D_s^+ mesons:

  sensitive to **charm** hadronisation via coalescence
- Non-prompt D_s^+ mesons: from B meson decays (5-10%)

  sensitive to **beauty** hadronisation via coalescence

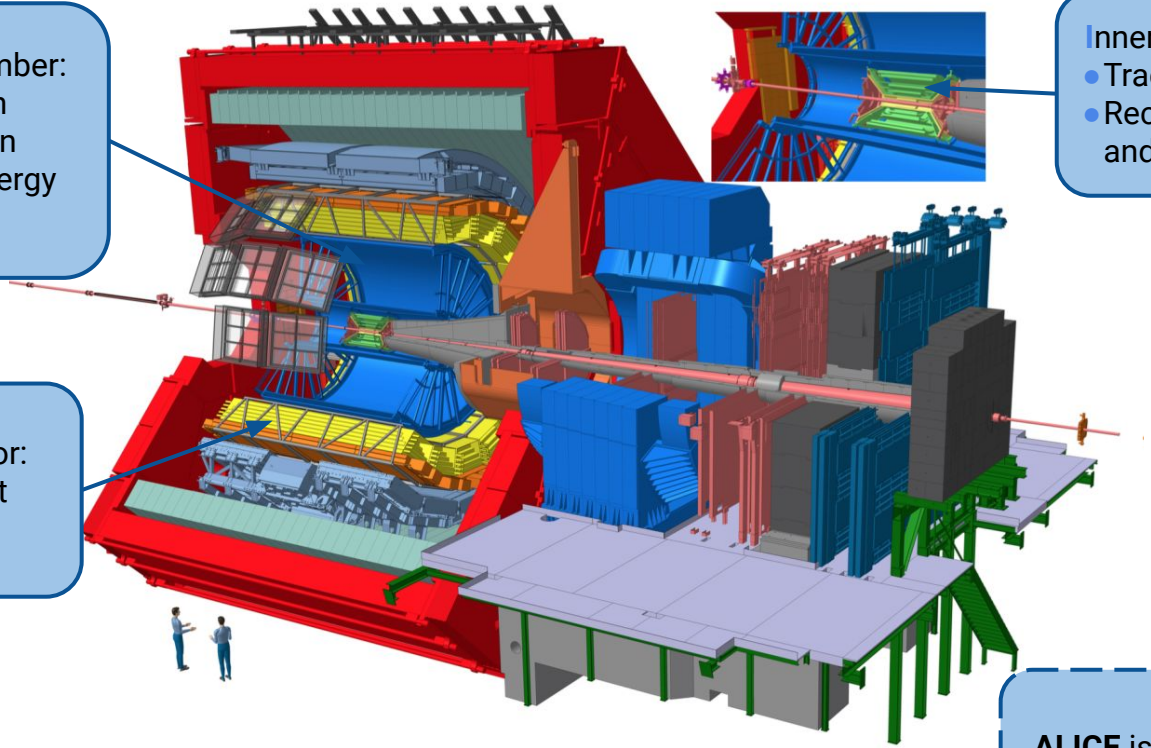


PRC 84 (2014)034906

A Large Ion Collider Experiment

Time Projection Chamber:
- Track reconstruction
- Particle Identification (PID) via specific energy loss

Time Of Flight detector:
- PID via time-of -flight measurements



Inner Tracking System:
- Tracking
- Reconstruction of primary and decay vertices

ALICE is specifically designed to study QGP and strong interaction

Analysis strategy

Selection of candidates

- **Machine Learning (ML) multi-class classification** (`XGBoost`):

  3 classes: prompt D_s^+, **non-prompt** D_s^+, combinatorial **background;**

- ML model **training:**

  exploiting different decay-vertex topologies and PID information;

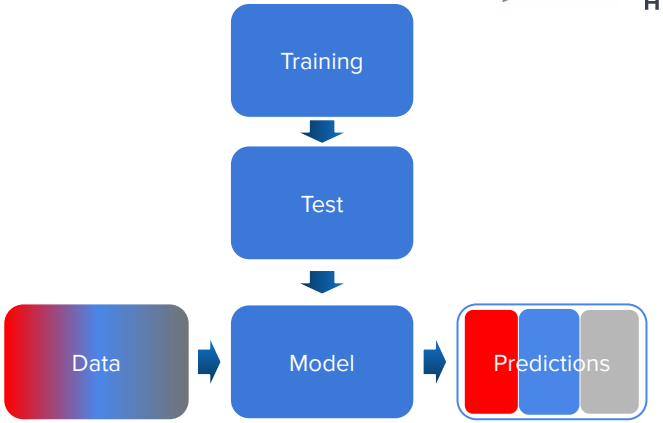
- ML model **application:**

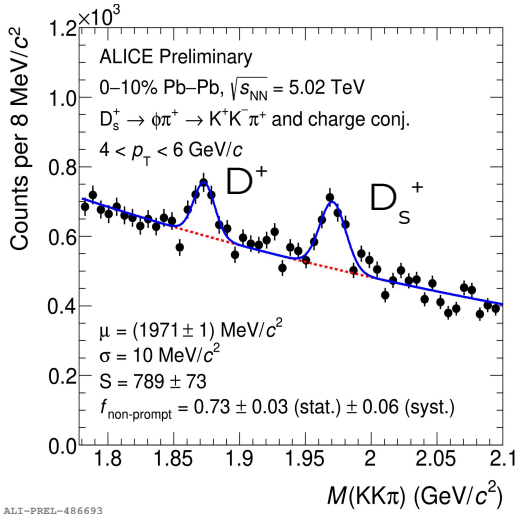
  3 output scores related to candidate probability belonging to each class;

Working point optimisation

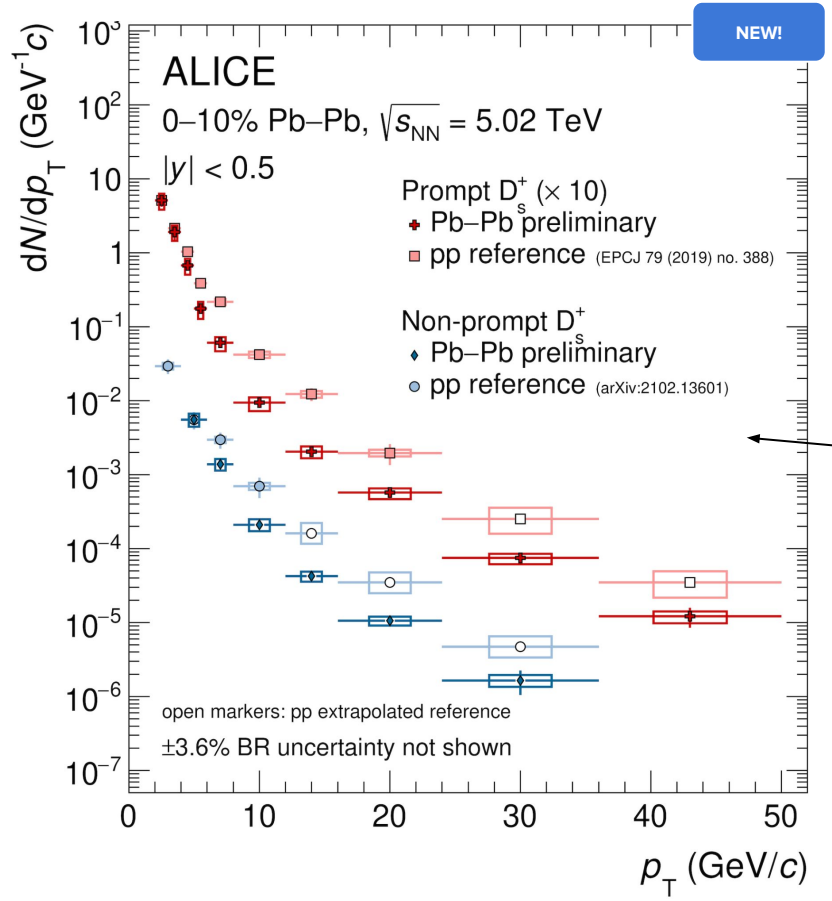
- **trade-off** between significance and non-prompt D_s fraction

Corrected yields





D_s mesons corrected yields



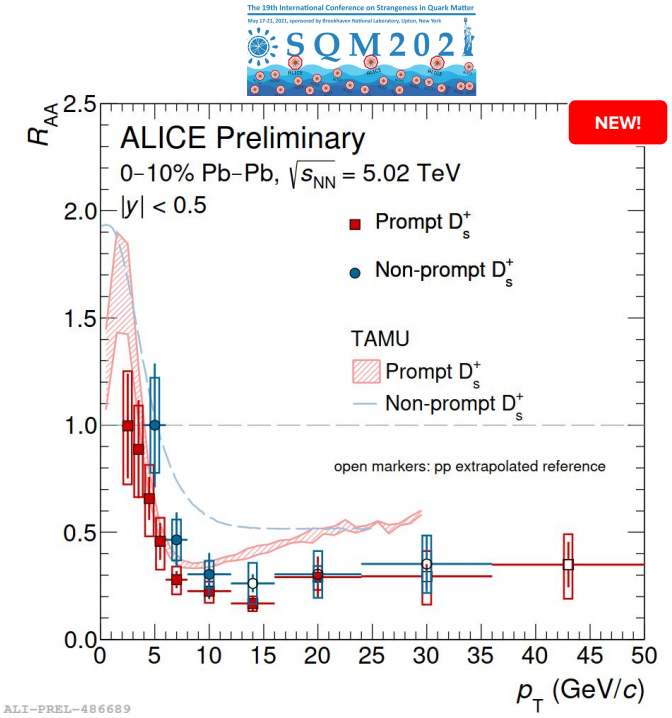
- Prompt D_s corrected yields
  - Pb-Pb: alice-paperdraft-id[6807]
  - pp reference: EPCJ 79 (2019) no. 388
- **Non-prompt D_s corrected yields**
  - Pb-Pb: data-driven method
  - pp reference: arXiv:2102.13601
- $$R_{AA} = \frac{1}{\langle N_{coll} \rangle} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

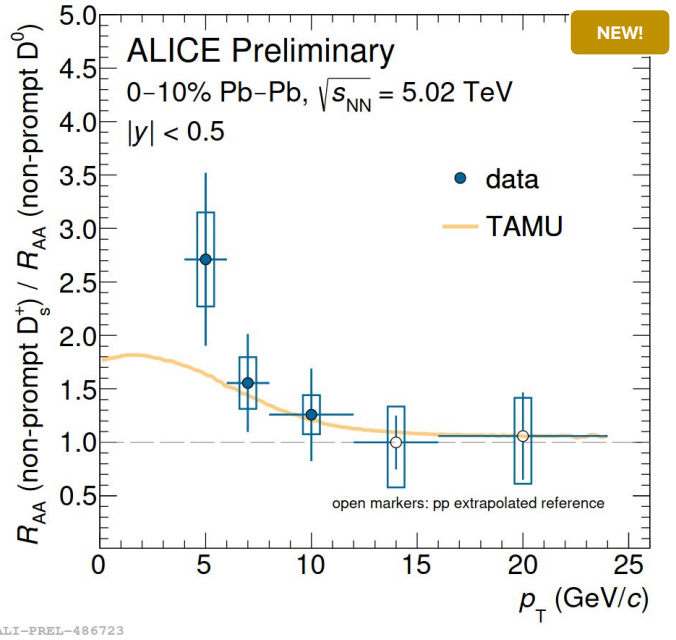
  dN_{AA}/dp_T → production yield in pp collisions

  $\langle N_{coll} \rangle$ → binary nucleon-nucleon collisions
  - expected to be **equal to unity** if no modification induced by nuclear environment (see A. Kalweit *"Ultra-Relativistic Heavy Ion Physics I"*)

ALI-PREL-486678

R_{AA} comparison with other D meson





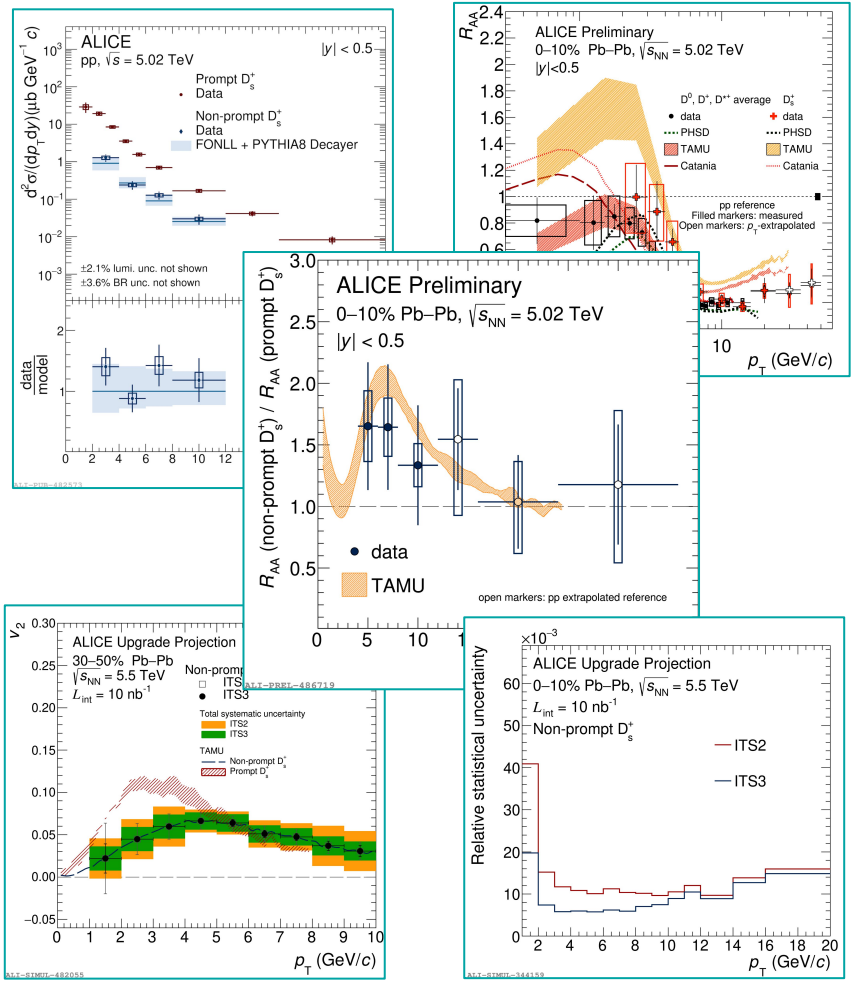
- R_{AA}(prompt D_s): **increasing** due to **higher energy loss in the medium** of the charm quark
- R_{AA}(strange)/R_{AA}(non-strange): **increasing** due to **enhanced production of B_s** from beauty hadronisation via coalescences

TAMU: M. He et al. PLB 735 445-450 (2014)

Outlook & Conclusions

- In Pb–Pb collisions **non-prompt D^+_s measured for the first time**
  - Insights into heavy-flavour hadronisation via recombination
  - Study of quark-mass mass dependence of in-medium energy loss

- Just an **appetizer** for ALICE measurements of **Run 3** with upgraded detectors and larger data samples!
  - **Major upgrade of ALICE** detectors and read-out electronics ongoing!

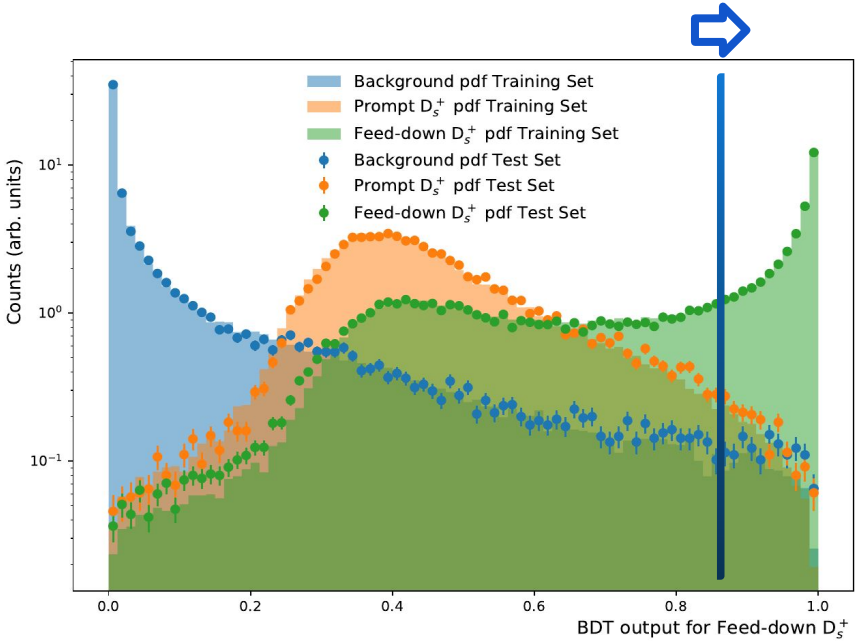


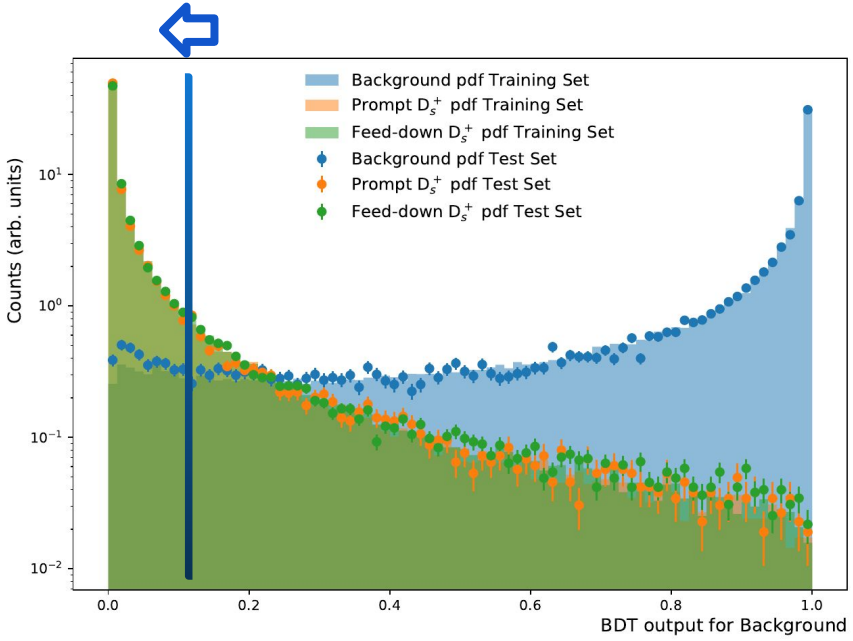
Backup Slides

ML model application (4 <p_T< 6 GeV/c)

Output score associated to each candidate as the probability to be prompt, non-prompt D_s and bkg

- Use only two output score given that $prob_{Prompt} + prob_{non\text{-}prompt} + prob_{bkg} = 1$
- ML-based selections applied on Non-prompt D_s & Bkg ML output scores:
  - **NP**: select candidates with high probability to be non-prompt
  - **Bkg**: select candidates with low probability to be background





Data-driven non-prompt fraction estimation

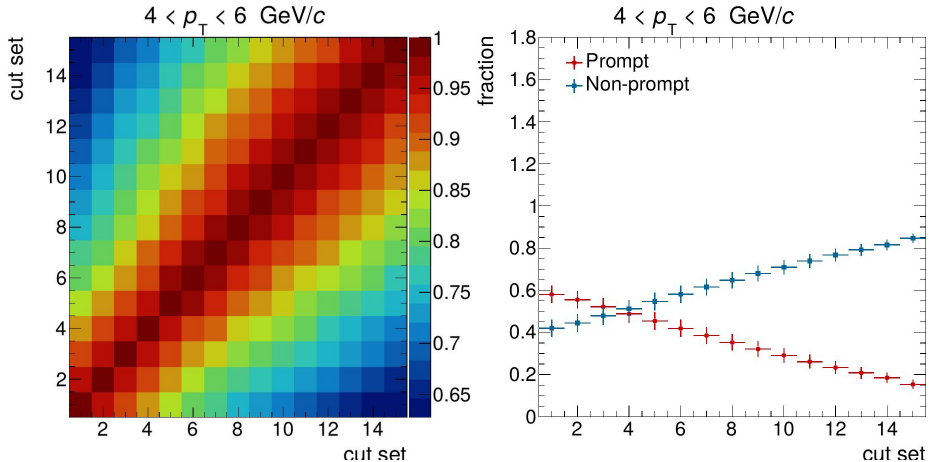
- n set of selections are employed
- each set is equivalent to an equation with 2 variables (N_{prompt}, N_{FD})
- system of equations is overdetermined: approximated solution obtained by minimising a χ^2
- from the approximated solution, the non-prompt fraction can be estimated

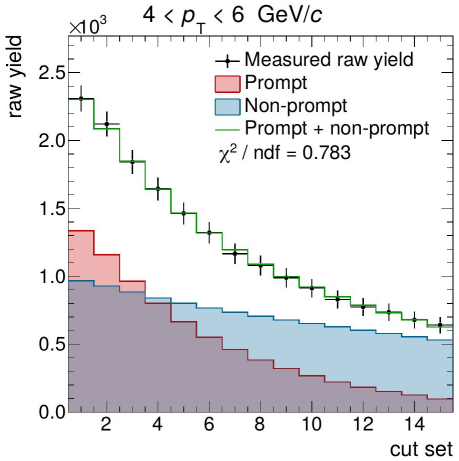
$$\begin{cases} \epsilon^1_{prompt} \cdot N_{prompt} + \epsilon^1_{FD} \cdot N_{FD} = Y^1 \\ \vdots \\ \epsilon^n_{prompt} \cdot N_{prompt} + \epsilon^n_{FD} \cdot N_{FD} = Y^n \end{cases}$$

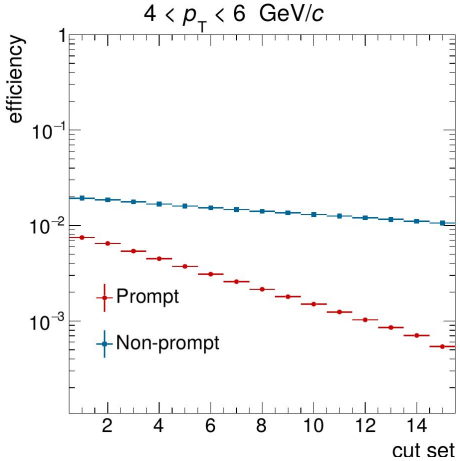
$$\begin{pmatrix} \epsilon^1_{prompt} & \epsilon^1_{FD} \\ \vdots & \vdots \\ \epsilon^n_{prompt} & \epsilon^n_{FD} \end{pmatrix} \times \begin{pmatrix} N_{\text{p}} \\ N_{\text{np}} \end{pmatrix} - \begin{pmatrix} Y1 \\ \vdots \\ Y_n \end{pmatrix} = \begin{pmatrix} \delta_2 \\ \vdots \\ \delta_n \end{pmatrix}$$

$$f^j_{FD} = \frac{\varepsilon^j_{FD} N_{FD}}{\varepsilon^j_{FD} N_{FD} + \varepsilon^j_{prompt} N_{prompt}}$$

Non-prompt fraction p_T 4-6 GeV/c





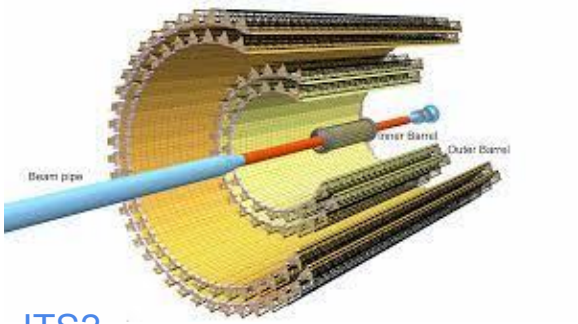


Prospects of Run 3 and beyond

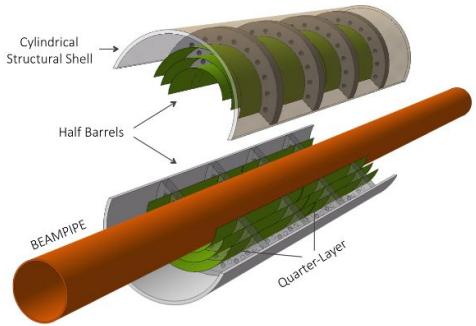
Major upgrade of ALICE detectors, read-out electronics and software ongoing

- ITS crucial for heavy-flavour measurements
  - ➡ ITS2: completely new detector
  - ➡ ITS3: truly *cylindrical* layer based on ultra-thin curved sensor

	ITS1	ITS2	ITS3
# of layers	6	7	7
X/X_0	1.14%	0.38%	0.05%
radius (mm)	39	22	18
pixel size (μm^2)	50x425	30x30	O(15x15)



ITS2



ITS3